Challenges and Solutions in Locating and Interpreting Microseismic Events from Surveys in the Horn River Basin

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Microseismic monitoring with downhole sensor arrays in the Horn River basin poses some unique challenges and constraints. The Horn River shales generally produce a large number of high magnitude events regularly allowing for viewing distances of 1200+ m. Some of the challenges come from the limited access with sensor arrays and the complex velocity structures that can include significant faults which occasionally cause some unexpected event distributions. Long travel paths of the signal in a complicated velocity model create complex wavefields with multiple arrivals. Identifying the different arriving waveforms correctly is essential to achieve optimum location accuracy. Forward modeling of waveforms and traveltimes can anticipate some of the challenges which is especially important for getting reliable event locations in (quasi) real-time. Understanding these challenges and limitations of a given acquisition geometry is possible before any data acquisition occurs. Location accuracy, the effects of velocity anisotropy and potential areas of reliable moment tensor inversions can all be anticipated ahead of the data acquisition and the sensor array position and configuration or the interpretation itself can be adjusted accordingly.

Introduction

Microseismic monitoring in the Horn River basin poses some unique challenges when compared to other shale gas plays. The often high downhole temperatures of up to 170^o Celsius and the remoteness of the location require a robust, reliable acquisition system. Fit-for-purpose observation wells are rarely possible in these surveys, limiting the options for sensor placement considerably. The Horn River shale is also microseismically a very active formation producing a large number of high magnitude events. Although this makes event detection often less a challenge compared to other formations, the large observational distances of more than 1200+ m require careful consideration of the sensor array configuration, placement and processing technique to achieve the optimum location accuracy. In addition, there are numerous indications that the complex velocity model is even more complicated by faults in the area that can facilitate extensive downward growth or diversion of fluids from different stages into the same areas. Although often there is not enough information available to explicitly account for anisotropy in the velocity model, at the very least a sensitivity study can show what its potential effect on the event location and the interpretation could be. This is also important for advanced characterization of the event as the inversion for source parameters often depends on the event location as well.

Assessing Location Accuracy

Assessing the effect of different sensor array configurations and positions on the location accuracy requires at least a qualitative definition of location accuracy. For a grid search method this measurement can be the fit between the identified and the calculated arrival times. Contouring these traveltime residuals (Figure 1) provides a quantitative measure of the expected location accuracy for an event with a particular pattern of arrival times. If the arrival times are allowed to randomly vary up to a certain threshold, the resulting event locations (black circles in Figure 1) trace out the corresponding residual contour. The shape and size of the residual contours depends on the toolstring position, the underlying velocity model and the data quality, and the shape can be quite irregular. The grid point with the smallest residual is considered the most likely location for the event.

Beyond the pure event location, the source mechanism of the individual events can provide further insight into the effectiveness of the treatment. A full moment tensor inversion describing the source mechanism depends on observations of the event from different viewing angles. When using a single observation well, the area where reliable moment tensor inversions can be performed is limited by the relative location of the event to the sensor array. Knowing these limitations is essential before interpreting the calculated results.

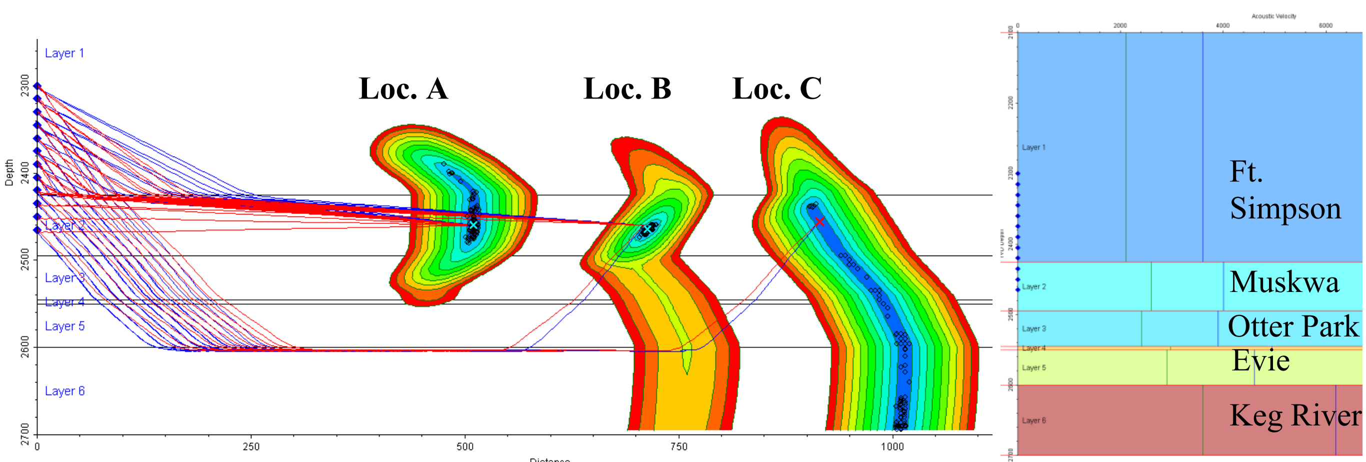
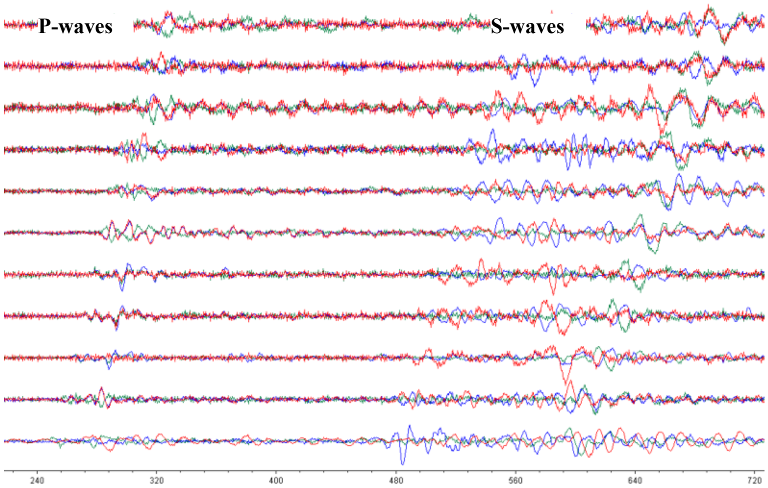


Figure 1: Generic Velocity model in the Horn River basin

A typical velocity model through the Horn River shales and adjacent formations (Figure 1 (right)) includes the relatively homogenous Fort Simpson followed by the Muskwa and Otter Park shales that are higher in P- and S-wave velocity. In some areas of the Horn River basin the Otter Park is followed by the thin high velocity layer of the Middle Devonian Carbonate (MDC). The Evie formation underlies the Otter Park (and MDC) and usually has a higher velocity than the Muskwa and Otter Park formations. Below the Evie is the high velocity Keg River carbonate.

The length and position of the sensor array has an impact on the location accuracy. Sensor arrays close to reservoir level have the highest sensitivity for event detection and the mostly horizontal travel paths of the seismic wave reduces the impact of any VTI-type anisotropy in the model. More importantly the phases used in the localization of the event have an impact on the depth accuracy of the event location. In Figure 1 an event at location A uses only direct waves for localization giving a small depth uncertainty (dark blue contours). Location B is further away but has an apparent smaller depth uncertainty caused by the use of direct waves **and** headwaves for the localization. Assuming that the velocity in the refracting layer is calibrated properly and that the headwave can be identified in the recording, this provides a better depth constraint than the direct wave solution alone. For Location C only headwaves are used to locate the event which results in a very large depth uncertainty. To avoid this situation the sensor array could either placed higher in the observation well or the analysis could switch from the first arriving headwaves to the later arriving larger amplitude direct waves. Switching the localization method is preferred over the repositioning of the sensor arrays as higher positioning of the sensor array results in larger viewing distances and a larger anisotropic effect. In cases where the headwave and direct wave are clearly visible both phases can be used simultaneously to locate the event and constrain the solution better than first arrivals or direct waves alone.



The large viewing distances and complex velocity structures in the Horn River basin create complex wavefields (Figure 2). Identifying the different phases, e.g. headwaves, direct waves, conversions and reflections (Figure 3), correctly is essential for providing accurate maps of the event distribution.

Figure 2: Typical waveform of a distant (1400m+) microseismic event with a complex P- and S-wave arrival pattern

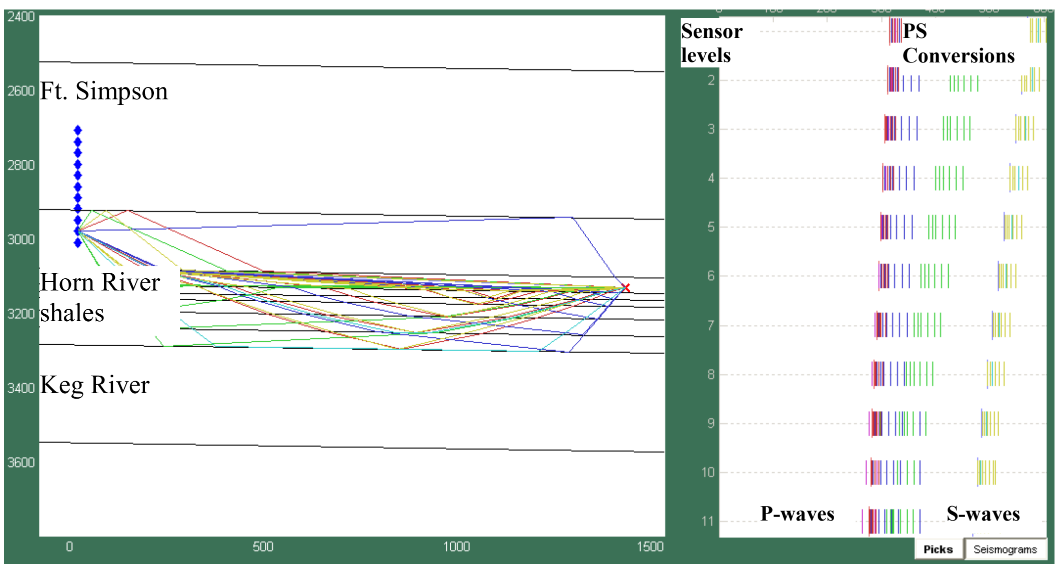


Figure 3: Seismic ray paths and arrivals for a typical microseismic survey in the Horn River basin

Anisotropy in the velocity model can lead to additional uncertainty in the event location if not properly accounted for. Where enough clear events in known locations, e.g. perforation shots, are recorded, the effective anisotropy parameters can be estimated. Alternatively, the degree of anisotropy can be used as an additional parameter in the calibration procedure. Depending on the degree of anisotropy, the general velocity structure, the event location and the relative position of the sensor array to the event location, the calculated event can be significantly off the true location (Warpinski et al. 2009). Quantitative information on the anisotropy in the Horn River basin is still very limited. In the absence of reliable quantitative information, sensitivity studies with reasonable parameter intervals provide at least semi-quantitative information that can be incorporated in the interpretation. This is especially important for acquisition geometries where the sensor array is placed high above the target formation as the ratio of horizontal to vertical travel path changes with the event distance from the array.

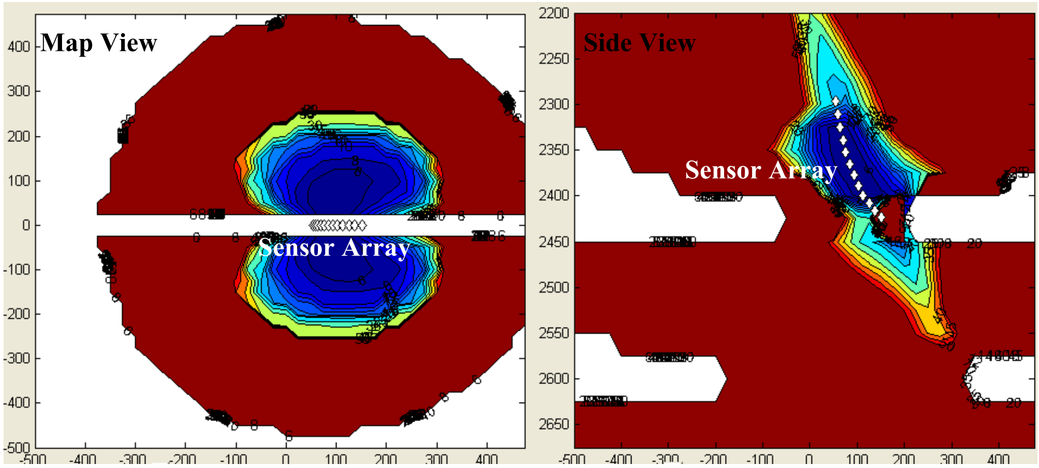


Figure 4: Distribution of the condition number for moment tensor inversion

For favorable acquisition geometries additional event properties beyond its spatial coordinates can be calculated. Many methods, e.g. Brune model, constrain the possible source mechanism. For a full description of the event source it is necessary to calculate all six elements of moment tensor. But the area where reliable moment tensor solutions can be calculated is limited by the acquisition geometry reflected in the distribution of the condition number. Figure 4 shows the distribution of the condition number for a single deviated toolstring in map view (left) and side view (right). Only in areas with blue contours is the moment tensor inversion stable enough to produce meaningful results. These figures show that the area where reliable source parameters can be calculated is relatively small. This area cannot be increased by assuming high quality data as it is mainly constrained by the acquisition geometry itself and the underlying velocity model. Only adding sensors in different positions will increase the area where stable moment tensor solutions can be calculated. For a typical single sensor array the area of reliable moment tensor inversions extends only a few hundred meters into the rock mass, which excludes much of the monitored area of approx 1200+ m around the sensor array. Although a low condition number is necessary for a reliable moment tensor inversions, the location uncertainty, too, can have a significant impact on the accuracy of the moment tensor inversion.

Conclusions

The Horn river basin provides a challenging environment in acquiring, processing and interpreting microseismic data. Although event quantity is almost never an issue when mapping hydraulic fracture treatments, the constraints on the acquisition geometry and limited calibration data requires a thorough understanding of the expected waveforms, location uncertainties and limitations of the survey for a reliable interpretation.

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References

Warpinski, N.R., Waltman, C.K., Du., J., Ma., J. (2009), Anisotropy Effects in Microseismic Monitoring: Presentation at the 2009 Annual Technical Conference and Exhibition, SPE124208.